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Do property rights in waste and by-products matter for promoting reuse, recycling and recovery? Lessons learnt from northwestern Europe

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ABSTRACT

Within the context of concurrent global waste and resource crises, there is significant interest in promoting circular economies. One of the identified ways to facilitate greater circularity is through replicable practices of industrial symbiosis, where industries and other organizations exchange waste and by-products resulting in economic, environmental, and social benefits. This paper investigates the role of a particular critical legal mechanism – property rights – in enabling industrial symbiosis by drawing on the experiences of waste and by-product exchanges within three industrial symbiosis case studies located in Kalundborg (Denmark), Peterborough (United Kingdom), and Rotterdam (the Netherlands). In order to determine whether property rights are incentives, facilitative mechanisms, barriers, or opportunities, the Schlager-Ostrom taxonomy is applied. Case findings evidence that different property regimes can have facilitative effects on circularity within industrial symbioses. There is thus no absolute support presumed in favor of one particular property rights regime over others; property regimes are flexible and hence allow for case specificity.

1. Introduction

Current global resource consumption and waste production are at unsustainable levels. Annual global primary resource extraction and use has exceeded 100 billion tonnes per year since 2017, while simultaneously more than 2 billion tonnes of municipal solid waste is generated annually and could increase by 70% by 2050 (Kaza et al. 2018; Circle Economy 2020). The circular economy concept has emerged as one of the possible resource and waste management strategies to mitigate these resource and waste crises (e.g. Geissdoerfer et al. 2017). Circular economies aim to transition away from the traditional linear take-make-dispose approach, which 'wastes' waste and is resource intensive, towards the prevention of wastes and 'looping' of any wastes produced and resources through reuse, recycling, and other recovery for economic, environmental, and social benefits (Kirchherr et al. 2017).

Industrial symbiosis networks, in which wastes and by-products are exchanged between different organizations, are identified as a circular economy implementation (de Abreu and Ceglia 2018; Merli et al. 2018) and have been explicitly recognized in non-binding European Union (EU) policy documents as a supportive strategy for achieving similar environmental, economic, and social benefits to circular economies. Industrial symbiosis networks are, for example, recognized as a strategy for facilitating the circular economy in the EU's new Circular Economy Action Plan (European Commission 2020), as well as sustainable consumption and production in the Roadmap to a Resource Efficient Europe (European Commission 2011), and resource efficiency in the European Resource Efficiency Platform (European Commission 2012). More recently, and arguably more significantly as a result of its legally binding nature, industrial symbiosis is included in the Waste Framework Directive 2008/98/EC (WFD) (Directive 2008/98/EC on waste and repealing certain directives, 2008) as a result of amendments made by Directive 2018/851 (amending Directive) (Directive 2018/851 amending Directive 2008/98/EC on waste, 2018) to Article 5(3) to allow adoption of certain criteria by Member States to "prioritise replicable practices of *industrial symbiosis*" (emphasis added). This is in order to contribute to the overarching WFD objective to lay down measures that prevent or reduce waste generation, impacts of waste management and generation and impacts of resource use, "which are crucial for the transition to a circular economy" (Article 1).

A central question is thus: what mechanisms can enable the development of industrial symbiosis practices? While several facilitative mechanisms have been explored in the literature, including a platform enabling information and knowledge exchange (Raabe et al. 2017), an internet-based market mechanism (Clayton, Muirshead and Reichgelt 2002), and Information and Communications Technology tools (Grant et al. 2010), scholars have identified the need to further investigate and develop understanding of extant industrial symbiosis case studies, as well as the incentives

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fostering industrial symbiosis (e.g. Domenech et al. 2019; Neves et al. 2020). This paper contributes to this literature by exploring the role of a specific legal paradigm – property rights – within selected existing industrial symbiosis networks (see Section 2). This discussion is both timely due to the increased recognition of industrial symbiosis benefits and their role in achieving circular economies, but also because of ongoing scholarly discussions on property rights for effective environmental management of resources (e.g. Hanna et al. 1995; Libecap 2009), which is at the core of industrial symbiosis and circular economy.

The rationale for and contributions of focusing on property rights within the industrial symbiosis context are three-fold. First, property rights are at the core of exchanges while thus far being under-explored in industrial symbiosis literature and its wider field of industrial ecology; who owns and is responsible for wastes and other resources determines what can enter industrial symbiosis systems. The limited literature on property rights has an economic rather than legal focus. Sathre and Grdzelishvili (2006, 387) state that the role of government interests in developing industrial symbiosis is a "question of public versus private responsibility for waste and pollution, and intrinsically linked to the issue of property rights", but do not expand on this. Similarly, there is no discussion or elaboration beyond identification of property rights as one of the challenges within industrial ecology by Giurco et al. (2014) and Laybourn (2005). Desrochers (2012) and Behne (2016) only mention property rights in relation to them underpinning the economic dimension of industrial ecology. Very limited prior research thus exists and has adopted a legal approach to property rights in industrial symbiosis (and similarly in circular economies more widely – see Steenmans et al. 2020). This paper fills this void by examining the possible effects of property rights in three case studies of industrial symbiosis networks.

Second, waste is increasingly regarded as a valuable resource, evidenced by the amending Directive highlighting "that waste is valued as a resource" (Recital 2). The term 'resource' has connotations of value, and is sometimes even defined by reference to it (e.g. Merriam-Webster 2018; Oxford English Dictionary 2018). How value is perceived may in turn be affected by ownership and attribution, and therefore property rights (Leopold 1968).

Finally, there are many theoretical discussions regarding the significance of ownership in resource management – whether privatization, government intervention, or other institutions are most appropriate (e.g. Hardin 1968; Welch 1983; Ostrom 1990; France-Hudson 2017; Thomas 2019). These debates and discussions have been applied within numerous contexts (e.g. Berkes 1987; Lange and Shepheard 2014; Malcolm and Clarke 2017). Similar discussions are warranted within the context of industrial symbiosis to consider the most appropriate property right interventions to promote industrial symbiosis practices more widely.

The remainder of the paper is structured in four parts. First, the research design is described and explained. The second part introduces the case studies and examines the property regimes present in each of them. These findings are then discussed in the following section. The final section concludes and identifies further research.

2. Materials and methods

This section first sets out the research question, followed by two sections detailing the data collection and analysis methods. The research design is summarized in Fig. 1.

2.1. Research question

The research question framing this paper is: what is the role of property rights in enabling industrial symbiosis systems in the EU? Within legal research and practice, boundaries are important as they determine what is and is not covered by the law, and when (Lieber 1838; Thayer 1908; Cheyne and Purdue 1995; Steenmans 2018). For this reason, the terms 'property rights' and 'industrial symbiosis' are described below. What is meant by 'enabling' and how it is evaluated in this paper is set out in Section 2.3.3.

Property rights are understood in this paper as a "man-made institution" (Macpherson 1978, 1) that describes the nature of rights in resources (Clarke and Kohler 2005). The framework adopted to understand and analyze property rights is described in Section 2.3.3.

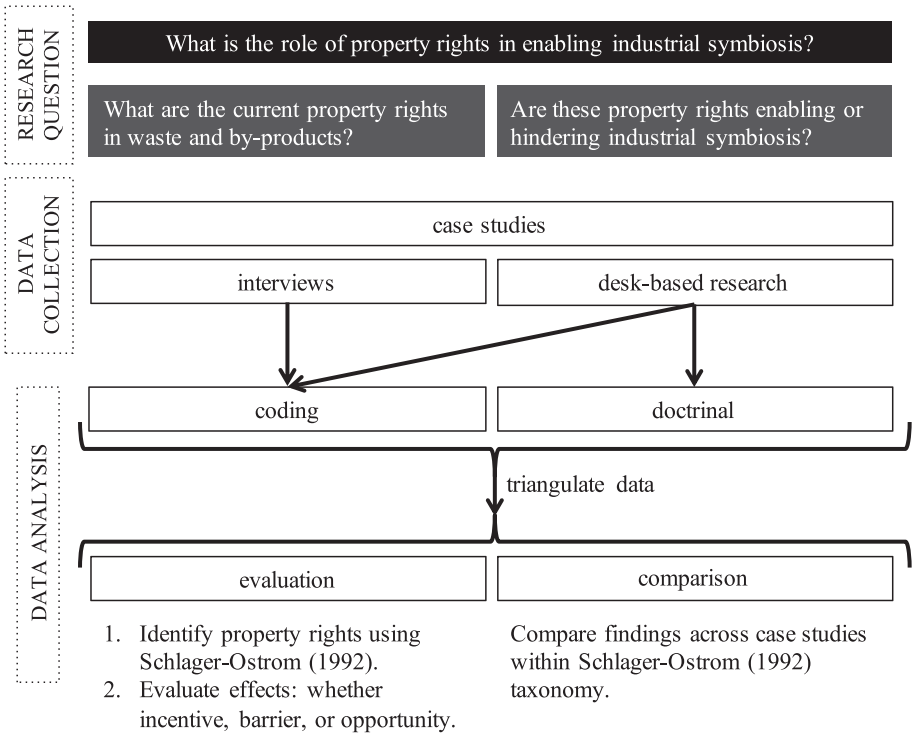

Fig. 1. Research design.

Industrial symbiosis engages traditionally separate industries and other organizations in a collective exchange of wastes and by-products resulting in economic, environmental, and social benefits.[1] This definition combines Chertow's (2007) seminal scholarly definition with definitions included in the EU's policy documents (European Commission 2011; see also European Commission DG Environment News Alert Service, 2012; European Commission, 2012). In essence, the exchanges within industrial symbiosis systems comprise the reuse, recycling, or other recovery of waste and by-product streams, which result in economic, environmental, and social benefits (e.g. Lowe and Evans 1995; Chertow and Lombardi 2005; Hashimoto et al. 2010; Morales et al. 2019). Industrial symbiosis is thus a particular manifestation of the circular economy, with circular economies covering materials more widely (beyond waste and by-products) and at more levels (macro in addition to micro and *meso* levels) (Kirchherr et al. 2017; de Abreu and Ceglia 2018; Merli et al. 2018).

Key terms within the definition of industrial symbiosis warranting further explanation are waste and by-products. Within the EU, waste "means any substance or object which the holder discards or intends or is required to discard" pursuant to Article 3(1) of the WFD. This definition has been the subject of numerous EU cases (Case C-9/00, 2002; Case C-235/02, 2004; Case C-304/94, 1997; Case C-444/00, 2003; Case C-457/02, 2004; Joined Cases C-206/88 and C-207/88, 1990; Joined Cases C-241/12 and C-242/12, 2013; Joined Cases C-418/97 and C-419/97, 2000) and resulted in a lack of clear and definitive characteristics, which have in turn been much discussed in the literature (e.g. Fluck 1994; Cheyne and Purdue 1995; Van Calster 1997; Tromans 2001; Malcolm and Clift 2002; Scotford 2007; Edwards 2013; Steenmans et al. 2017).[2] These issues are not clarified at national level, with the definition of waste transposed word per word in the national legislation of the selected case studies (see next section). The impact is however limited as the definition of waste is generally cast broadly (Case C-176/05, 2007; Case C-188/07, 2008; Case C-252/05, 2007). Thus, uncertainty in a substance or material being waste means a cautious lawyer would advise to treat it as waste (Steenmans 2018). Waste can stop being waste as a result of the end-of-waste criteria set out in Article 6 of the WFD. The discussion pertaining if and when waste stops being waste is beyond the scope of this paper as it does not affect the actual property rights involved – though it may affect their perception – when the substance or material is produced or changes hands (Steenmans and Malcolm 2020).

Instead of the intended product or waste, by-products may be produced in production processes. Pursuant to Article 5(1) of the WFD (as amended), by-products must meet the following four conditions: certainty of further use; use without further processing other than normal industrial practice; product of integral part of production process; and further use is lawful, that is the substance of object "fulfills all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts" (Article 5(1)(d)). There are uncertainties associated with these conditions – e.g. what qualifies as 'integral' and 'normal' (Steenmans 2018) – but these are yet to be discussed in EU case law. Similarly to waste, the by-product criteria are transposed into the national law of the selected case studies (see next section).

The terms 'waste' and 'by-product' are used interchangeably with 'resources' throughout this paper. This approach resonates with the view adopted by interview participants.

2.2. Data collection

The research adopts a mixed-methods approach combining empirical research with desk-based and doctrinal research. This approach is applied for three reasons: triangulation, facilitation, and complementarity (Hammersley 1996; Bryman 2008).

A multi-case study method is used to explore the particularity and complexity of property rights within real-life industrial symbiosis contexts (Yin 2009). The three selected case studies provide useful insights into the role of property rights in waste: despite historically being criticized for not being able to contribute to scientific development, it is possible to generalize based on one case study with the value of examples often undervalued (Flyvbjerg 2006).

The selected industrial symbiosis case studies are in: Kalundborg (Denmark), Peterborough (United Kingdom (UK)), and Rotterdam (the Netherlands). The case study selection criteria were: location, exemplary outcome, access, and language.

First, the cases selected are all within the EU,[3] which provides some uniformity in the regulatory and policy frameworks via the harmonizing effect of EU law. For example, the definition of waste is exactly the same in the Waste Ordinance (Bekendtgørelse af lov nr 1309 af 18.12.2012 om affald some aendret, 2012) in Denmark; the Environmental Protection Act (Wet milieubeheer, 1979) in the Netherlands; and the Environmental Protection Act 1990 in England as in the WFD. In relation to by-product, the term is not used in the Danish Waste Ordinance, but the concept is still present as materials meeting the by-product criteria are not classed as waste. In the Netherlands and UK, by-products are defined by reference to the WFD in the Dutch Environmental Protection Act and Waste (England and Wales) Regulations 2011 respectively. The identical definitions do not indicate that the *governance* of waste and by-products is identical across the case studies, but it provides at the very least a common baseline. Property rights are not harmonized at EU level due to different legal systems (see below), though Article 36(1) of the WFD dictates that waste cannot be abandoned (i.e. owners cannot unilaterally cede their ownership).

Second, the cases were selected using replication logic instead of representation, which requires every chosen case to demonstrate the occurrence of exemplary outcomes (Yin 2009). This is defined as those meeting Chertow's 3–2 heuristic, as this starts recognizing complex relationships rather than linear one-way exchanges (Chertow 2007). The heuristic requires a minimum of three different entities, of which none are engaged primarily in a recycling-oriented relationship, exchanging at least two different resources. Moreover, the case studies are more than eco-industrial parks as the entities include consumers.

Third, access was based on availability of resources on the case studies and access to possible interview participants.

Finally, cases were selected in countries where the researcher had the requisite language skills to read policy and regulatory documents.

Case study data was collected through interviews and desk-based research. Desk-based research reviewed extant literature, and EU and national laws mainly to understand the case studies, and to triangulate and validate data. Semi-structured interviews were conducted between 2015 and 2017. The open-ended questions on property rights included: Are you aware of the property rights in the industrial symbiosis? What is the role of property rights? Follow-up questions were asked (depending on preceding responses), including: In your opinion, would it be possible to rethink property rights by extending responsibility to the manufacturer so that they have to take goods back instead of selling them? Are communal property rights something that you think can be further explored? These questions were thus focused on understanding the perception of property rights by practitioners and experts, to compare and contrast with the actual assigned property rights in law (see Section 2.3.3). Interviews were audio recorded, and then transcribed for analysis.

Sixteen interviews (eight in Kalundborg, five in Peterborough, and three in Rotterdam) were conducted with representatives from industries and other organizations exchanging wastes or by-products in the industrial

[1] For a detailed discussion on how this definition has been amended see Steenmans (2018).

[2] The EU case law and literature on the definition of waste are reviewed in detail in Steenmans (2018).

[3] The UK triggered the process to leave the EU on 29 March 2017 with the process allowed to take up to two years. At the time of researching this paper, the UK was still a Member State of the EU. Currently, the UK remains subject to EU law, including the WFD, until at least 31 December 2020 as a result of the transition period.

symbiosis (hereafter referred to as symbionts) and third parties (i.e. stakeholders, including municipalities and research organizations, that have a role in the initiation and sustainment of industrial symbiosis, but are not symbionts themselves). When the same information was being repeated by interview participants, this indicated that sufficient interviews had been conducted. As far as possible, participants were selected of similar capacity and levels across the three case studies.

2.3. Data analysis

Data from desk-based research and interviews were coded, with additional doctrinal research methods adopted for laws. This data was triangulated before being evaluated and compared. These analysis methods are detailed below.

2.3.1. Coding

Coding is used in qualitative inquiry to organize, sort, and analyze data (Charmaz 2006). A code is a word or short phrase that "assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of … data" (Saldaña 2012, 3). An inductive approach was used to develop the codes through identifying repeated themes and terms through two cycles: first to identify initial codes, and then to check and confirm these codes.

2.3.2. Doctrinal law

Even though the doctrinal research method is used, this paper cannot be categorized as a piece of doctrinal research as case studies and interviews are also employed. Doctrinal research "focuses almost entirely on law's own language of statutes and case law to make sense of the legal world" (Morris and Murphy 2011, 31); it comprises identifying, analyzing, and synthesizing the content of law, including the identification and exposition of ambiguities and inconsistencies (Posner 1981; Hutchinson 2013). This process was mainly applied to EU and national waste laws relating to definitions of waste and by-products to understand the legal implications of the terms, and to check whether they considered or addressed anything relevant to property rights.

2.3.3. Evaluation of property rights

Evaluation looks at what does and does not work, and why and how (Pawson and Tiley 1997; Pawson 2013). A two-step evaluation process was adopted to: (1) identify the existing property rights regimes; and (2) assess their effects. For the first step, a taxonomy was used to facilitate understanding by clarifying what property regimes are present based on the presence of certain property rights.

Traditionally, property rights regimes have been described as private, communal, state, or no property (e.g. Waldron 1988; Bromley 1989; Clarke and Kohler 2005). This characterization is not without its limits as it arguably "renders invisible many new forms of property" (Heller 2000, 417), but it can provide a useful analytical tool as long as it is acknowledged that the boundaries "fray at the edges" (Heller 2000, 418) and that these "ideal types are almost never found in practice. In most cases there are overlapping sets of rights, 'underneath' the general classifications" (Barry and Meinzen-Dick 2014, 298). The Schlager and Ostrom (1992) taxonomy adopted and applied in this paper can help understand these overlaps.

Schlager and Ostrom subscribe to the notion that property is a 'bundle of rights' metaphor (e.g. Demsetz 1967; Penner 1996; Johnson 2007; Ellickson 2011). This taxonomy is relevant to this research as it was developed in relation to research on common-pool resource systems, as which industrial symbiosis networks have been described (Steenmans 2018). Common-pool resource systems comprise natural or man-made "resource systems and a flow of resource units or benefits form these systems" (Ostrom 2002, 39; see also Ostrom 1990).

Schlager and Ostrom, drawing on Commons (1924) and Ciriacy-Wantryp and Bishop (1975), identify five separate bundles:

1. *Access*: the right to enter a defined property;
2. *Withdrawal*: the right to obtain resource units or products of a resource system;
3. *Management*: the right to regulate internal use patterns and transform the resource by making improvements;
4. *Exclusion*: the right to determine who will have an access right, and how that right may be transferred; and
5. *Alienation*: the right to sell or lease either or both of the management and evolution rights.

Table 1
Schlager-Ostrom taxonomy. Adopted from Schlager and Ostrom (1992).

	Authorized entrant	Authorized user	Authorized claimant	Proprietor	Full owner
Access	X	X	X	X	X
Withdrawal		X	X	X	X
Management			X	X	X
Exclusion				X	X
Alienation					X

These rights do not need to be simultaneously present. Schlager and Ostrom arrange these bundles across five classes of user as shown in Table 1: full owner, proprietor, authorized claimant, authorized user, and authorized entrant.

Private property has been described as "that sole and despotic dominion which one man claims and exercises over the external things of the world, in total exclusion of the right of any other individual in the universe" ((Blackstone II, 1765-1769) 2). There is therefore a legal entity that is the full owner of the private property holding all five bundles. According to Locke (1980), one way private property can come about is by man mixing labor with the elements of the natural world so it becomes that person's property (called Locke's labor theory).[4] State property is similar to private property in that the state (or other public body) is the full owner and holds all five bundles. But, in practice the state will often permit individuals and groups to access the property, such as public parks (Barry and Meinzen-Dick, 2014). Communal property is where each member of the community has the right to (1) access the property, and (2) not be excluded from it. All members of the community are therefore proprietors. No property (also known as 'res nullius') is where everyone can access the resource but no one has an enforceable right to this access against others or the state – so everyone can enter and withdraw, but no one is an authorized entrant or other class of user.

A limit of applying the Schlager-Ostrom taxonomy is that the bundle of rights approach is not widely accepted in civil law (Orsi 2014). There are, however, numerous examples where Schlager-Ostrom's taxonomy of rights are applied in civil law systems without acknowledgement of the possible ingrained conflict (e.g. Bouriaud and Smithüsen 2005; Stebek 2011; Baur and Binder 2013). This can be justified using Mattei's (2000, 13) argument that "[t]he bundle metaphor can easily be adapted … It will be enough to clarify that different [rights] might be missing in different legal systems".

Once the property rights are identified, the next step is to evaluate their 'enabling' effects. This is informed by what is and is not possible under those property regimes, which determines whether they are incentives, barriers, or opportunities in the context of the case studies. In this paper, incentives are defined as mechanisms that actively motivate an exchange to take place; facilitative mechanisms enable exchanges but do not have causal impacts; barriers stop or limit an exchange; and opportunities are where there is potential for property regimes to become an incentive. The relevant impact(s) of property rights in the case studies was determined by the nature of the rights together with what was conveyed during interviews.

2.3.4. Comparing case studies

In reviewing property rights and national laws, the different jurisdictions of the case studies must be acknowledged – the UK has a common

[4] There has been much discussion of Locke's labor theory in the literature. See for example Waldron (1984), Judge (2002), and Widerquist (2010).

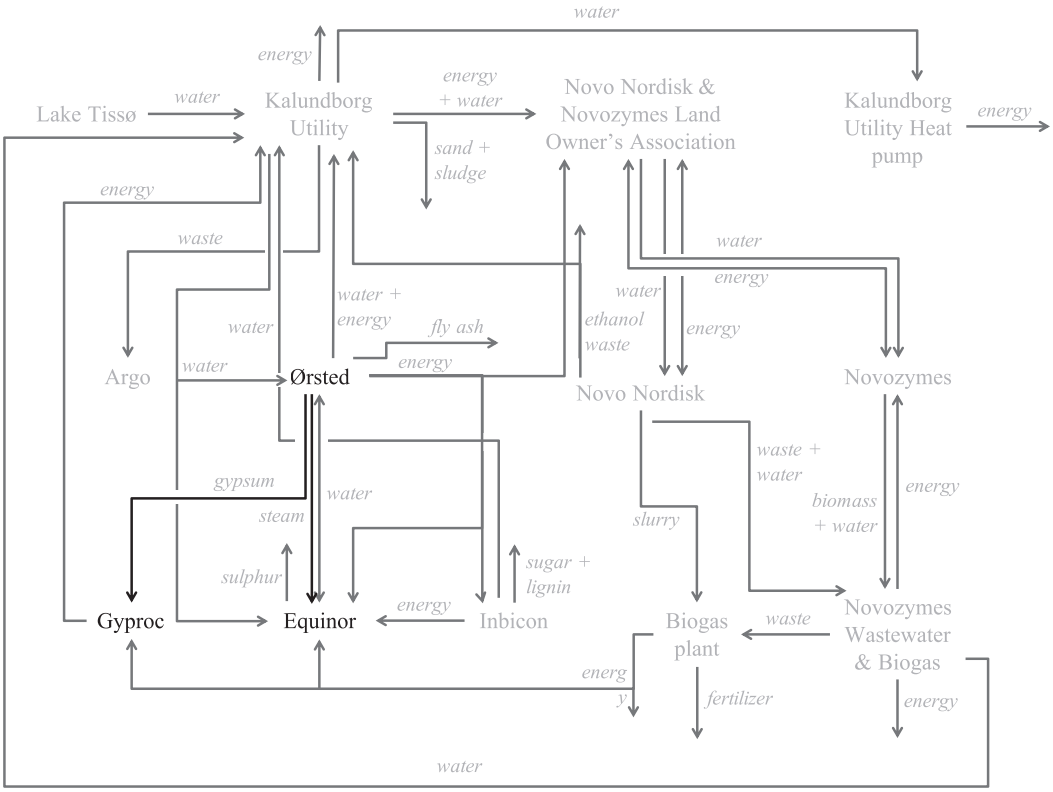

Fig. 2. Kalundborg industrial symbiosis. Based on Kalundborg Symbiosis (2018).

law system, while Denmark and the Netherlands have Scandinavian and Napoleonic civil law systems respectively. The similarities and differences between these systems are not examined in this paper, as this is unnecessary according to mainstream comparative methods in legal research (Siems 2014). Despite differences, there are many commonalities between the two systems (e.g. human rights, the rule of law, and a positive and rational law) and often differences are misleading or exaggerated. Legal rules often apply in similar ways, particularly as the case studies are limited to Western legal systems (Siems 2014). However, it is necessary in relation to comparing their property systems.

Civil and common law property systems are "coherent within themselves but difficult to reconcile" (van Erp 2006a). Some of the key differences identified are in their approaches to ownership and title; in civil law there is a strict separation of property from obligations while in common law "many of the lesser estates look something like very long-term relational contracts" (Chang and Smith 2016, 139); common law systems arguably have a larger and more open-ended set of property rights; and common law still differentiates between land, personal property, and trust law, whereas general principles and rules exist in civil law for all forms of property (van Erp 2006b; Chang and Smith 2016). Despite apparent differences between the details of civil and common law property regimes, there is increased recognition that the leading principles underlying policies, fundamental concepts, and basic rules are quite similar, and that they may therefore be compared to a certain degree in comparative studies (Mattei 2000; van Erp 2006a, 2006b; Dalhuisen 2013).

3. Results: case studies

The case studies are set out below, with the focus limited to two exchanges within the industrial symbiosis networks in order to focus the discussion.

3.1. Kalundborg industrial symbiosis

The seminal example of industrial symbiosis is located in Kalundborg with at least 13 key symbionts exchanging 28 resources, presented in Fig. 2.[5] The exchanges in the Kalundborg industrial symbiosis – including the water from Lake Tissø and steam sold by Ørsted to Equinor – are controlled by commercially negotiated contracts, most often between two parties (Ehrenfeld and Gertler 1997; Jacobsen 2002; Jacobsen and Anderberg 2004; Domènech and Davies 2011; and confirmed by interview participants). The contracts include clauses on the prices for the resource exchanges for a set period, payment terms, and mechanisms for future changes (such as escape clauses and requirements for upgrading) (Gertler 1995; Jacobsen 2002; Chertow, 2004). They evidence that symbionts can sell their wastes and by-products, and are able to exclude and alienate them from others. These resources are thus currently predominantly treated as private property with the relevant symbionts as full owners in Schlager-Ostrom terms. Contracts and private property rights provide the certainty and security that many companies require to minimize their risk in industrial symbiosis.

The treatment and perception of property rights in gypsum are both private, but the treatment of steam as private property differs from the usual perception of steam. Steam has been described as "the ultimate externality" because it usually leaves the premises in the form of an atmospheric emission (Steenmans et al. 2017, 10). It is most often treated as res nullius, comparable to greenhouse gas emissions that are produced by all symbionts but over which no one claims full ownership. Either can currently be justified legally. The steam is produced by and belongs to Ørsted, but usually its form (and perceived lack of value) prevent entities from claiming full

[5] This is the minimum number, as arguably further symbiotic exchanges exist. For example, there is an H&M in Kalundborg where households can return clothing waste for reuse, recovery or recycling as part of their H&M garment collecting initiative (H&M 2018).

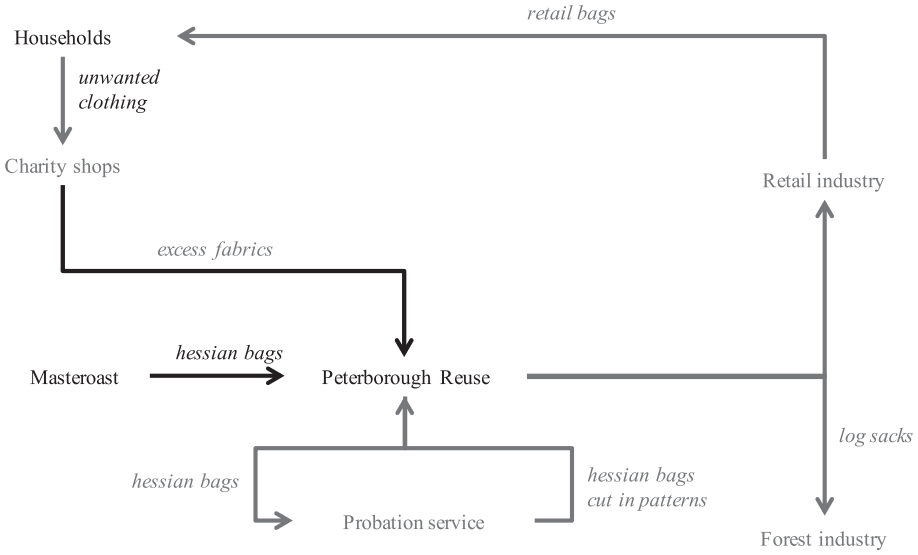

Fig. 3. Peterborough industrial symbiosis. Based on interview data and Peterborough Reuse (2017).

ownership. Even if steam was determined to be res nullius, then the capturing of it by Ørsted would be sufficient to apply Locke's labor theory – as collecting is sufficient to constitute labor – and then still become private property (Locke 1980).

The perception of private property rights facilitates symbiotic exchanges through enabling the commodification of wastes and by-products; both wastes and by-products are perceived and treated as tradable economic goods of (monetary) value. This was evidenced during the interviews with, for example, one interview participant stating that the exchanges are perceived as "quite a good business deal," and another participant that companies see waste as a good that "can be sold … or you can [save] money by buying another company's waste."

There is one exception to the above discussion on private property exchanges; the water supplied by Lake Tissø is state property to which other legal entities (including individuals) are given access (e.g. fishing and sailing) and withdrawal rights (e.g. for industrial symbiosis purposes). As state property is a particular form of private property, the previous arguments still apply. Some argue that water should instead be res nullius or communal property (as commodification of water is considered "inappropriate") (Clarke and Malcolm 2016, 121; see also: Malcolm and Clarke 2017), but it would then still become private property as a result of Kalundborg Utility mixing their labor with the water (Locke 1980).

3.2. Peterborough industrial symbiosis

A meeting in April 2015 between Peterborough Reuse Limited, Opportunity Peterborough (a not-for-profit company wholly owned by Peterborough City Council), and Masteroast Coffee Company Limited (a roasting and packing facility) resulted in the initiation of a symbiotic system in Peterborough, UK, repurposing coffee sacks and unwanted clothing into bags. Currently, Masteroast provides Peterborough Reuse with more than 1400 hessian and jute sacks every week. The sacks are first cleaned and processed before being sent to offenders and ex-offenders to cut into shape. The materials are then turned into retail items (including reusable bags) and log sacks for tree planting, the forest industry, and riverbank reinforcement against flooding by a group of local and predominantly long-term unemployed, recent migrant, or stay-at-home women recruited and trained by Peterborough Reuse and the UK Department of Work and Pensions (Masteroast 2016). The retail bags are lined with excess fabric, which is bought from local charity shops and in some instances received as donations from households. This system is represented in Fig. 3.

As in Kalundborg, the hessian bag exchanges are mainly governed by contracts, and symbionts have the complete bundle of Schlager-Ostrom rights that mean they are private property. There are, however, instances where the property rights are less clear-cut. Some excess fabric used by Peterborough Reuse for lining its retail bags were provided by individuals that intended to discard the fabrics (i.e. waste according to the WFD), but had not yet physically discarded them. In essence, they are the full owner in Schlager-Ostrom terms, but do not exercise their power to exclude or alienate others and only want to exercise their rights as authorized claimants. According to an interview participant, the actual full owners instead perceive the excess fabrics as communal property that the local community can access.

The divergence between legal reality and the perception of property rights in excess fabrics is comparable to a scenario where neighbors place furniture outside their house with the intention for it to be taken by another household. But, English case law demonstrates that there are limits to this. For example, individuals have faced or been threatened with prosecution in recovering food waste from bins outside food stores (The Guardian 2014; BBC 2011), even though recovering food for consumption from state-owned bins in public spaces is considered acceptable despite also legally being private property of the state (Steenmans and Malcolm 2020). Furthermore, in the English case of *Williams and Others v Phillips* and *Roberts and Others v Phillips* (1957) dustmen employed by a waste management corporation were convicted of stealing goods from dustbins collected in the course of their duties, selling the goods to dealers, and sharing the proceeds. Lord Goddard CJ (*Williams and Others v Phillips and Roberts and Others v Phillips, 1957*, 8) said:

> If I put refuse in my dustbin outside my house, I am not abandoning it in the sense that I am leaving it for anybody to take it away. I am putting it out so that it may be collected and taken away by the local authority, and until it has been taken away by the local authority it is my property.

Thus in England, where waste is left does not matter – whether curbside or in dustbin – as the transfer of property does not occur until collected by the intended entity. These examples demonstrate that there is no legal uncertainty in relation to property rights, but that context, intention, and social norms affect the perception of property rights.

The perception of communal property rights in this case has been facilitative of industrial symbiosis, though not incentivized, as the motivation was mainly social (the training of women) and environmental (prevent 'wasted' hessian and jute sacks) (interview participants).

3.3. Rotterdam harbor industrial symbiosis

Previous research has focused on industrial symbiosis in the Rotterdam port (e.g. Baas 1998, 2000; Baas and Boons 2004; Baas and Korevaar 2011).

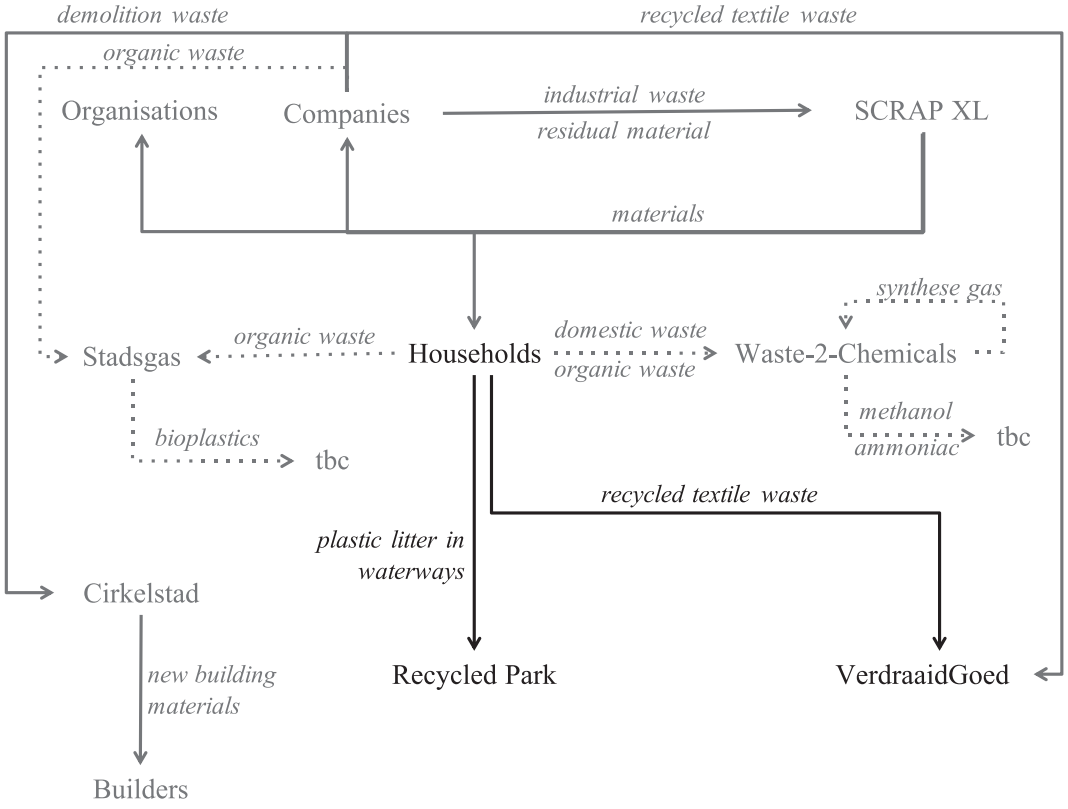

Fig. 4. Rotterdam industrial symbiosis. The dotted lines indicate that the project is still being developed – ranging from the conceptual to piloting stages. Developed based on interview data and Rotterdam Climate Initiative (2018b).

First, there was the INdustrial EcoSystem (INES) Project, which was extended and re-labeled the INES Mainport Project (1999–2002). Between 2003 and 2010 the INES project was included in the R3: Sustainable enterprises project, together with the Sustainable Rijnmond and Energy 2010 programs, under which it faltered and was hardly known (Baas and Korevaar 2011). Since 2007, the focus has been on the Rotterdam climate Initiative (2018), which is a new development rather than a direct replacement of INES as no evidence indicates that the Initiative was aware of INES. The Rotterdam Climate Initiative is the umbrella framework under which the Port of Rotterdam Authority, Deltalinqs, DCMR Environmental Protection Agency Rijnmond, and the City of Rotterdam collaborate to deliver a sustainable world port city (Rotterdam Climate Initiative, 2018a).

A number of smaller projects have developed independently that focus on circular approaches within the Rotterdam port – these are not a result of the Initiative but fall within its scope. These are presented in Fig. 4. This paper focuses on the Recycled Park Project and Verdraaidgoed.

The Recycled Park Project, launched by WHIM Architecture and the Recycled Island Foundation, aims to catch plastic waste – larger plastic fragments rather than microplastics – in the New Meuse River in Rotterdam before it enters the North Sea. The plastic waste is then used to build a floating island on which there is a park for the Rotterdam community to use. Three litter traps have been developed and placed, and a 140m^2 prototype recycled park is open to the public. The goal is to place eight plastic litter traps in the river and expand the island to 190m^2 (Recycled Park 2018). The islands have been durably built to counteract the plastic breaking down in the water and contributing to the problem of microplastics (Herranz 2018).

Recycled Park is an authorized user of the plastic litter in Schlager-Ostrom terms, as they (together with everyone else in the world) can access and withdraw littered plastics from the river. They are not authorized claimants as they cannot manage the littered plastics in the New Meuse River – they had to apply for the necessary permits to place the traps into the river. The littered plastics are thus perceived as res nullius. Through the labor of collecting and transforming plastic waste into an island, Recycled Park becomes the authorized claimant as they manage the island. Recycled Park could become a proprietor or full owner, but the aim is for the island to be communal, so that everyone has the privilege to enter the island and right not to be excluded or alienated.

These perceived property rights differ from the legal reality. The plastic litter has been unlawfully abandoned and littered, pursuant to the Dutch Environmental Protection Act (Wet milieubeheer, 1979) and the Rotterdam Waste Regulation (Afvalstoffenverordening Rotterdam, 2009).[6] Their most recent previous legal owner therefore technically still owns the plastic litter in the river. Given that in practice there is often no method of identifying them, the plastic waste is instead perceived as res nullius. The absence of property rights is a driver of industrial symbiosis in the case of the Recycled Park; if littered plastics were treated as private property, they would not be retrieved from the river before entering the sea from where retrieval is more expensive (Jambeck et al. 2015).

More typical of the industrial symbiosis is the example of VerdraaidGoed, as part of which reusable bags are made from residual materials such as old flags, promotion banners, and shop window canvas drapes similar to the Peterborough example (VerdraaidGoed 2018). Households have been full owners and used their alienation right to transfer management to VerdraaidGoed. Private property in such examples therefore enables the symbiotic exchanges (as in Kalundborg and Peterborough). These are often motivated by environmental reasons rather than economic, as there is not always monetary value attached to these exchanges.

[6] Chapter 10(25) of the Dutch Environmental Protection Act states that regulations may be made to prevent littering, which are enacted in Rotterdam by the Rotterdam Waste Regulation with paragraph 4 setting out the unlawfulness of littering for Rotterdam.

Table 2
Comparison of property rights in case studies.

Resource	Resource type[a]		Exchange		Perceived v actual reality	Schlager-ostrom taxonomy					Property regime				Impact		
	Waste	By-product	Business-to-business	Consumer-to-business		Authorized entrant	Authorized user	Authorized claimant	Proprietor	Full owner	Communal	Private	Res nullius	State	Incentive	Facilitative mechanism	Barrier	Opportunity
Kalundborg																		
Gypsum		✓	✓		Perceived	✓	✓	✓	✓	✓		✓				✓		
					Actual	✓	✓	✓	✓	✓		✓				✓		
Steam	✓		✓		Perceived	✓	✓	✓	✓	✓		✓				✓		
					Actual	✓	✓	✓					✓			✓		
Peterborough																		
Hessian bags	✓		✓		Perceived	✓	✓	✓	✓	✓		✓				✓		
					Actual	✓	✓	✓	✓	✓		✓				✓		
Unwanted clothing	✓			✓	Perceived	✓	✓	✓			✓					✓		
					Actual	✓	✓	✓	✓	✓		✓				✓		
Rotterdam																		
Plastic litter	✓			✓	Perceived	✓	✓	✓					✓		✓			
					Actual	✓	✓	✓	✓	✓		✓					✓	
Recycled textile waste	✓			✓	Perceived	✓	✓	✓	✓	✓		✓				✓		
					Actual	✓	✓	✓	✓	✓		✓				✓		

[a] Based on interview participants' perspectives and application of the WFD definition.

4. Discussion

The case study findings on property rights are collated in Table 2. Across all case studies, property regimes had received little or no explicit thought by interview participants and extant literature prior to this study, despite being inherent in industrial symbiosis exchanges.

There is no one-size-fits-all approach to property rights across the case studies to facilitate symbiotic exchanges; property regimes are flexible and hence allow for case specificity. Where the exchanges occur between businesses, the exchanges are generally private, with one notable exception of steam in Kalundborg as a result of the nature and form of the resource. Two of the exchanges involving consumers (i.e. unwanted clothing in Peterborough and plastic litter in Rotterdam) seem to allow different property rights (communal and res nullius respectively) based on the perceived reality. It was the desire to enact environmental and social benefits, specifically preventing waste ending up in landfill or the sea, and providing skills and work for specific social groups, that motivated the exchanges. These experiences contrast with the Kalundborg industrial symbiosis where exchanges were mainly motivated by economic factors (Jacobsen 2002; Sterr and Ott 2004; interview participants) and where waste is viewed as a commodity.

Perhaps unsurprisingly, some interview participants in the Peterborough and Rotterdam case studies stated that private property rights can be a barrier because they dictate what and how property can be considered and legally transferred – e.g. "[private property rights are] I suspect, one of the main barriers actually for people to move on" (Peterborough interview participant). In Rotterdam, plastic litter would not be retrieved from the river if it was perceived as private property, whereas perceived res nullius property rights were identified as potentially helping "create conditions for industry to progress" towards circular economies (Rotterdam interview participant). A similar argument can be made in Kalundborg; if property rights were not perceived as private, the economic incentive would not be present to initiate the exchange. In general, the perceived property rights were therefore facilitative mechanisms across the case studies, as they neither directly incentivize nor motivate the exchanges to occur, but also did not prevent them, with the actual property rights in some cases presenting a possible barrier.

Overall, the case studies thus simultaneously demonstrate that existing property regimes can be facilitative, but that their potential as outright incentives is not yet maximized. They still remain very much in the background of any discussion. To realize their incentivizing capabilities, changes in the law can and arguably should be implemented to make waste producers and holders aware of how waste can and should be sustainably managed to achieve circular economy and resource efficiency goals.

A possible legislative mechanism is identified in Article 8 of the WFD: Extended Producer Responsibility (EPR) (though the link with property rights is not made explicit in this provision). EPR shifts responsibility for waste management from the entities traditionally responsible – consumers and authorities – to the producers of products. EPR can exist in different forms: physical responsibility where the producer is responsible for the physical end-of-life management of its products (i.e. product take-back programs); economic responsibility where the producer covers all or part of the financial costs for end-of-life management of its products; liability where the producer bears responsibility for environmental damages by the product; and informative responsibility where the producer provides information on the product and its environmental effects across the life-cycle stages (Lindhqvist 2000; see also Steenmans 2019 for an overview of EPR within the EU WFD).

Property rights can be used to implement EPR measures, though further investigation is needed, which is beyond the scope of this study. Private property rights are commonly suggested as a mechanism for facilitating physical responsibility; producers may lease products, so that they retain ownership and the product is returned to them at the end of its life cycle (e.g. Clift 1997). The possible contribution of other property rights to physical responsibility, and the possible relationships between property rights and the other types of responsibility generally are not yet explored. Perhaps, producers could remain authorized claimants of products so that

they can manage them to ensure resource- and cost-effectiveness. Further research in this area should also cover property rights in relation to extending EPR to producer ownership schemes (e.g. UCL ISR and Systemiq 2019) and recasting EPR as pre-market producer responsibility in order to limit market access to durable, reparable, and reusable products (Maitre-Ekern 2021).

The potential of property rights in incentivizing industrial symbiosis is also recognized in practice; one interview participant noted the potential positive impact of private property rights and resultant economic incentives if one of the forms of extended producer responsibility is applied:

> If [companies] just lease the product instead of selling it … But, most people are not there yet because you need to see the value for that … you need to see where is your incentive, and for manufacturers it is mainly economic.

Communal property regimes can also be adopted to encourage more industrial symbiosis networks – either open access for everyone or limited to a defined group of entities and individuals. A community could have shared responsibility for the management of pooled waste and by-products, while also having the opportunity and privilege to consume it. Environmentally responsible entities within the community could then interfere with others' waste and by-products to ensure that they are managed properly. Communal property could, however, equally result in others using or managing wastes and by-products in an environmentally detrimental fashion, whether intentionally or negligently. Laws can and should be enacted to avoid such outcomes – these should be explored in further research. Similarly, res nullius property requires support by laws to ensure resources are managed effectively.

5. Conclusions

Industrial symbiosis has been identified as a conducive strategy for promoting and achieving a number of EU resource efficiency and circular economy policy goals (see Section 1), as well as international aims, such as the United Nations Sustainable Development Goals (Schroeder et al. 2019; Cecchin et al. 2020). There have therefore been calls for widespread implementation of industrial symbioses, but further research is needed on *how* this can be facilitated. This paper has contributed to this research gap by examining the role of property rights in enabling industrial symbiosis.

Property rights in waste and by-products need careful thought and consideration in different contexts, as they can affect how waste is conceived and treated. Yet, property rights are currently not consciously engaged with or used to incentivize development of industrial symbiosis practices.

Four possible property regimes were presented (private, state, communal, and res nullius) and there is evidence that all four can have positive enabling effects on industrial symbiosis. Private property regimes can result in the commodification of waste and see it treated as an economic good of value as in Kalundborg and Peterborough, but simultaneously a monetary incentive is not always necessary to achieve a private exchange for environmental purposes as in Rotterdam. Only the perception of a res nullius property regime was encountered in practice in Rotterdam. It resulted in certain stakeholders taking initiative to turn waste into something of value. Similarly, there was also only the perception of communal property rights that again enabled certain stakeholders to turn waste into a product perceived to have value. Finally, there was evidence of state property (Lake Tissø in Kalundborg and municipal solid waste in Peterborough), but these were not the main focus and require further examination.

There is currently no evidence to suggest that any of the three alternative property regimes is more conducive to promoting industrial symbiosis. It is therefore recommended that any contemporary selection of property rights is context dependent. The current EU context appears more favorable to private property regimes as they are central to the existing capitalist economy (e.g. Screpanti 1999), whereas communal property regimes would require a more fundamental shift in thinking about waste as a collective responsibility. Whichever property regime is intended to produce incentivizing effects would need further implementation of legal structures, as currently their potential is not being harnessed.

Questions remain on, for example, the responsibilities and duties the state should have in relation to wastes and by-products; whether communal ownership should be limited to a defined community (limited access) or include everyone in the world (open access); the legal and regulatory frameworks required to support and complement property regimes to ensure the desired resource management; and the impacts of the WFD's end-of-waste definition. In particular, further research is needed to explore the effects of all property regimes to elucidate their suitability as property regimes for incentivizing and facilitating replicability of industrial symbiosis and circularity. Such research needs to be complemented by investigations of law and policy tools that are dependent on the existence of a particular property regime and require or nudge waste producers or holders to manage waste in a particular manner by assigning particular duties. Examples of such mechanisms include product take-back programs, EPR, and other types of producer ownership schemes (e.g. UCL ISR and Systemiq 2019).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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